Atmospheric Deposition and Eastern Forests: Cooperative Research

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THE IMAGE

Starting somewhere in the boilers of factories and power plants, in the cylinders of our cars, and even in our home furnaces, sulfur and nitrogen are oxidized and are either released into the atmosphere as air pollutants, or interact with sunlight to form ozone. Buoyed by the winds, and nourished in chemically rich clouds, sulfur and nitrogen are converted into sulfuric and nitric acids. Once these compounds mix with moisture, they fall to the earth in the form of acid precipitation, popularly known as acid rain.

Acid rain—the name evokes a distressing image. Innocent raindrops that fall from the heavens to regenerate life in all its forms, instead, slowly and insidiously, burn the essence out of our lakes and streams and trees and soils. The popular media has exploited this image to get the public's attention; it is an image that distorts the facts about acid precipitation.

BEYOND THE IMAGE

What are those facts? Beyond the image, how do acid precipitation and ozone really affect our environment? Does the earth contain natural buffers that neutralize the acid's potential to do harm? Does the acid contain nutrients that are beneficial to plants? And what if the image is real, what must be done to stop, even reverse, the effects of acid deposition and ozone?

Researchers at the USDA's Forest Service Northeastern and Southeastern Forest Experiment Stations, the Environmental Protection Agency, and their cooperators have gone beyond the image to examine these and related questions. With long histories of involvement in acid deposition research, both Stations are participants in the National Acid Precipitation Assessment Program.

ACID RAIN: THE COMPLEX PHENOMENON

Natural vs. Human-made

It might be surprising to learn that pollution did not begin with the dawn of the Industrial Revolution or the first factory. In its natural form, pollution predates people by millions of years. In fact, the transport of foreign substances to distant ecosystems is as old as vegetation itself.

Pollution in nature can be spectacular—volcanic eruptions, wildfires, and lightning. Or it can be ordinary—salt from ocean spray and soil particles carried aloft in storms. Gases such as methane and hydrogen are pollutants in forest environments. So are spores and pollen when they are transported from their source. But we don't worry about natural pollution because the earth's ecosystems have adapted to it. Ozone occurs naturally high in our atmosphere where it filters out ultraviolet light that is harmful to life.

Human activities, however, are increasing the concentrations of naturally generated pollutants many-fold. In addition, people have created compounds that are unknown in nature. Today, our self-created pollution may threaten forest and urban trees and vegetation, fish and wildlife, soils, surface waters, and people.

Although the scientific community has focused attention on the causes and consequences of atmospheric deposition and ozone only in the last two decades, study into their effects is hardly new. As early as 1661, scientists in Europe pondered the possibility that industrial emissions could have a harmful influence on plants and people. In 1852, the term "acid rain" was first used by English chemist Robert Angus Smith. Smith noticed that precipitation in and around industrialized Great Britain was acidic. He blamed coal burning. Today, many researchers agree with Smith's conclusion. The major anthropogenic (human-made) sources of air pollution are the combustion of fossil fuels for power generation, space heating, and transportation, the smelting and refining of ores, and agriculture.

In fact, any emitted material—either human-made or natural— may contribute to acid deposition if it produces large amounts of free hydrogen ions in precipitation.

The extent of acidification of forests and waters caused by human activities is difficult to measure. Even normal variations in climate, such as drought, may affect deposition patterns and chemistry. Changing land use practices, weather patterns, and the acidifying nature of many normal soil and biologic processes, mean that isolating and identifying the impact of acid deposition is one of the greatest challenges facing researchers today.

Transport/Transformation

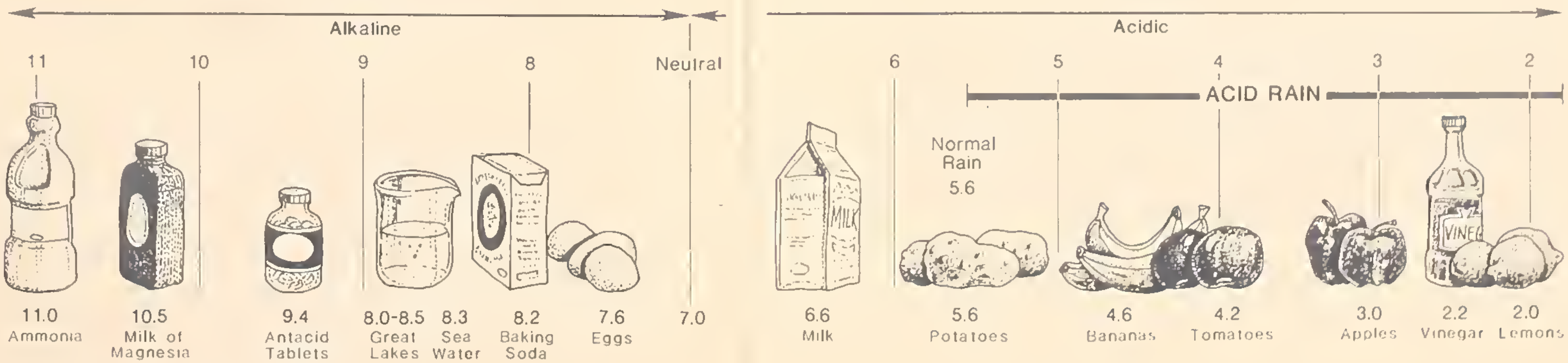
The whole phenomenon of acid deposition and ozone formation is made more complex because in this case what goes up usually does not come down in the same location. Emitted material may remain airborne for a long time—traveling many miles from the point of origin—before falling as wet or dry deposition or being converted by sunlight into ozone. Certain regions are said to be source areas, while other regions are receptor sites. More understanding of the transport and conversion process for acid rain is needed before we can say conclusively that emissions in city A cause acid rain to fall in city B, or on mountain C.

Wet vs. Dry

Acid precipitation and acid deposition are two forms of a phenomenon that scientists call atmospheric deposition. The term acid deposition includes both wet (rain or snow, mists, fogs, and sprays) and dry (sea salt, soil particles, atmospheric gases, and organic particles) depositions. Atmospheric deposition, the scientifically preferred term, is more inclusive and encompasses gases and particles from the atmosphere that are absorbed directly by foliage and soils.

Measuring Acidity: The Hydrogen Factor

The acid nature of a solution is measured by the concentration of hydrogen ions (pH). Using a logarithmic ranking system, the concentration of hydrogen ions is rated on a scale of 1 to 14; 7 is neutral; 14 is most alkaline, and 1 is most acidic. Normal precipitation has a pH of about 5.6; acid precipitation generally ranks between about 5.6 and 3.5, and in some cases even lower. Since the scale is logarithmic, and since the lower the number the higher the acidity, what appears on the scale as a decrease of only one unit, actually represents a 10-fold increase in hydrogen ion concentration.



Maybe It's Not All Bad: The Nitrogen Factor

The research community is debating the extent to which acid deposition helps or harms the terrestrial and aquatic systems of our forests. One of the components of acid deposition is nitrogen. Nitrogen is necessary for forest growth. In addition, acid rainfall contains nutrients such as potassium, calcium, and trace elements, often in a form readily available for plant use. Even the sulfur contained in deposition is beneficial to those soils which are sulfur deficient.

Too much nitrogen, however, is as bad as not enough. Elevated nitrogen content may predispose trees to winter damage. Nitrogen supplied to high elevation trees through cloud water may result in increased susceptibility to damage from early frost or desiccation.

The Interceptors: Acid Rain and Leaves

Forests are gas and particle scavengers—they clean acidified pollutants from fog, rain, and snow. But when leaves intercept the acidic properties in wet and dry deposition, chemical processes are set into motion that may stress the entire tree. Acid deposits on the leaf surface reduce the rate at which plants use sunlight to photosynthesize sugars. In addition, the nitrate component of acid deposition combines with the potassium component of the leaf's nutrient system. The potassium is then leached, or chemically washed from the leaf. If this vital potassium is not resupplied by the roots, the entire tree may suffer from nutrient stress. In addition to potassium, calcium, magnesium, and manganese are typically leached in large quantities. Alterations in leaf surface chemistry may increase vulnerability of the leaf to disease agents and toxic materials. Ozone can adversely affect and even kill leaf cells at concentrations well below one part of ozone in a million parts of air.

The Buffers: Acid Rain and Soils

Forest soils act as drains for a variety of air contaminants. Studies are under way to determine the ability of soils to buffer, or neutralize, the acidic component of these pollutants. We do know that acid deposits, over time, destroy the buffering ability of some soil types. Forest soils are particularly fragile because they are not limed as agricultural soils are. In a worst case scenario, highly acidic rain falling on soils that have lost the capacity to buffer the rain's acidic properties encourages the leaching of plant nutrients such as calcium, magnesium, and potassium. This accelerated loss of nutrients will eventually lead to decreased soil productivity followed by reduced tree growth.

Not only does acid deposition encourage the leaching of essential nutrients, but this phenomenon is also responsible for the dissolving of aluminum which is toxic in a soluble form. When aluminum is released from the soil, it runs off into lakes and streams. High deposits of aluminum, through direct and indirect effects, make it almost impossible for many forms of aquatic life to survive. Atmospheric deposition may also alter the function and structure of forest soils systems by increasing levels of copper, lead, and other trace metals.

Reproduction and Regeneration

Wet and dry deposition may alter the biochemistry of the forest system to the extent that the process of reproduction and regeneration is disrupted. Trace metals, elevated hydrogen levels, and other contaminants in the forest floor may reduce seed germination and the development of young seedlings. Ultimate changes in species composition may result in mixed species forests when species are affected differently by various pollutants.

THE EXPERIMENTAL FORESTS: LONG-TERM DATA BANKS KEEP THE RESEARCH PACE

Hubbard Brook Experimental Forest: Long-Term Data Bank

In 1955, the USDA Forest Service set aside a considerable portion of land in the White Mountains of New Hampshire exclusively for the conduct of research. Today, the Hubbard Brook Experimental Forest has become a primary source of data relating to acid precipitation. Precipitation chemistry, soil acidification, harvesting techniques, and aquatic systems have been studied continuously at this outdoor lab since 1963—the longest continuous record of this type in North America. As a result of data collected here, researchers have been able to discern some provocative trends about acid deposition and the effect it has on our forest system.

—Rainfall at Hubbard Brook has been acidic since 1963, the year precipitation chemistry record-keeping began, with an average pH of 4.1. However, the sulfur ion content, the major constituent of acid precipitation, has declined 20 to 30 percent in the past few years. This decline in the sulfur ion rate parallels the national decline in sulfur dioxide emissions.

—Storms that bring precipitation to Hubbard Brook come from sparsely populated regions, such as Maine and Quebec, and are usually low in acidity. These storms serve as a baseline for clear precipitation. Storms from the industrial Midwest, however, have between 8 and 10 times the acidity.

—Forest soils may lack buffering ability. With precipitation continuing to average pH 4.1, forest soils that have low nutrient availability and exchangeable bases could become more acidic by 1 pH unit (that is 10 times more acidic) within 30 to 50 years, without other compensating factors.

—Since shallow acidic soils do not adequately buffer incoming acid rain, streams originating near the tops of watersheds at Hubbard Brook are nearly as acidic as incoming precipitation.

—When a small stream that normally has a pH of 6 was adjusted so that it had a pH of 4, entire species of aquatic life were eliminated.

—Ponds that are able to produce abundant amounts of alkalines, or buffers, are unlikely to be adversely affected by acid deposition.

Scientists from many foreign countries have visited Hubbard Brook. It is the only site in the northeastern United States to be designated a Biosphere Reserve in the Man and the Biosphere Program. Data collected at this experimental forest greatly influence directions taken in acid deposition research, and ultimately in setting national policies regarding acid deposition as an environmental hazard.

Coweeta Hydrologic Laboratory: Inputs and Outputs

For more than 50 years, Forest Service scientists and their cooperators have been measuring and analyzing precipitation and streamflow on the heavily instrumented watersheds at the Coweeta Hydrologic Laboratory in western North Carolina. They measure what comes in from the atmosphere, and what leaves in the streams. The original purpose was to measure effects of land uses and forest treatments on the quality and quantity of stream water, but since 1970, researchers discovered that the same watersheds could be used to measure flows of nutrients and pollutants through forest ecosystems. Since then, detailed records of precipitation and streamflow chemistry have been maintained. Dry and wet deposition are measured.

The unique research opportunities at this outdoor laboratory have attracted scientists from all over the world. Cooperating scientists and technicians from Georgia, Emory, Virginia Polytechnic Institute, Clemson, Georgia Tech, North Carolina, Duke, and Michigan State universities usually outnumber Forest Service employees here. Over the past 15 years, more than 30 Ph.D. dissertations have been based upon data gathered at Coweeta, and some of the research has been financed by the National Science Foundation. Coweeta has been designated a Biosphere Reserve in the Man and the Biosphere Program.

Important research on air, soil, and water pollution is under way.

—Dry deposition has been shown to be an important source of pollution.

—Over the past 11 years, pollutant loadings have varied widely among storms, but long-term changes have been small.

—Ozone concentrations sufficient to injure and discolor eastern white pine needles have been observed.

—Most of the sulfur from acid rain has been captured by the forest floor materials and the soil beneath. The chemical transformations of sulfur and the role of microorganisms in the process have been described.

—Flows of nitrogen and other nutrients have been traced through Coweeta ecosystems.

—The chemistry of fog on southern Appalachian mountain slopes has been characterized.

These and other data will help the nation to make informed decisions about regulation of air pollution.

Northeastern Forest Experiment Station

The Northeastern Station now manages a research cooperative involving the Forest Service, the Environmental Protection Agency, universities, and private industry. Called the Spruce-Fir Research Cooperative, this effort's goal is to understand why Appalachian spruce-fir are declining.

Research on acid deposition is being carried out by Northeastern Station scientists at the Forestry Sciences Laboratory at Durham, New Hampshire, and at facilities at Burlington, Vermont; University Park, Pennsylvania; Parsons, West Virginia; Hamden, Connecticut; Delaware, Ohio; and Orono, Maine. Current research is being conducted in three vital areas: effects on aquatic ecosystems, effects on terrestrial ecosystems, and deposition monitoring. Projects carried out at Station laboratories form an intriguing interrelationship.

Results of this research may well dictate directions and decisive forms of action towards alleviating acid precipitation's potential to do serious harm.

Burlington, Vermont

Burlington scientists are determining the relationship of atmospheric deposition to the concentrations of major, minor, and trace elements in xylem sap, within tree tissues, on tissue surfaces, and in soil solution. These concentrations are simulated in excised tree shoots and seedlings in the laboratory to determine their effect on physiological systems and developmental events. In addition, scientists at Burlington are working to determine the role of atmospherically deposited nitrogen in red-spruce dieback and decline. Studies are under way to determine sapstream and foliage concentrations of nitrogen from healthy and declining stands. Through studying the effects of acidity and aluminum, scientists may be able to determine underlying principles of how aluminum affects trees, and how it interacts with other elements, essential for tree growth.

Delaware, Ohio

Scientists at Delaware are assessing and quantifying the effects of atmospheric deposition on forest structure, composition, and function. Studies are directed toward identifying the biochemical, physiological, and ultrastructural changes resulting from acid deposition and gaseous pollutants and subsequent effects on forest growth and processes.

Durham, New Hampshire

Scientists at Durham and at the University of Hamburg, Federal Republic of Germany, are working jointly to further our understanding of changing properties in declining trees and the relationship of decline to atmospheric deposition. Disturbances of wood and bark metabolites are being studied by observing changes in ions, phenols, and proteins at Durham. Disturbances of fine-root uptake associated with soil effects caused by acidic deposition are being studied by elemental analysis and stable isotope techniques at Hamburg.

In other work at Durham, researchers are studying the growth patterns of more than 11,000 increment cores collected from trees throughout New England. These cores are small cylinders of wood extracted by inserting a hollow tube from the bark to the center of each tree. The annual growth rings distributed along the length of the cores are measured, and as might be expected, some are wide (indicating good growing seasons) and others are narrow (because of drought, competition, insect attack, or other causes, including perhaps air pollution or acid rain). Continuing growth declines have been identified for red spruce since about 1960, and balsam fir starting about 1970. The Durham scientists are working with cooperators at Tuskegee University and Alabama A&M to determine whether there may be a pattern to these growth losses that is related to chemical and physical properties of soils.

Hamden, Connecticut

Hamden scientists and their cooperators at the University of New Hampshire, University of Vermont, and Yale University, are assess-

ing the role of natural disease causing agents in tree decline, and whether atmospheric deposition predisposes trees to these disease organisms. Studies on red spruce focus on relating root vitality to crown deterioration, determining the role of wind in inducing root damage and decay, and evaluating the interaction of acid deposition and root pathogens on seedling vigor and mortality. Other studies will examine the influence of atmospheric deposition on stem bark disease organisms, and will focus initially on the effects of stemflow chemistry, altered by atmospheric deposition, on the insect/fungus complex that causes beech bark disease.

Orono, Maine

Researchers at Orono are gathering data on the soil nutrient status of a wide variety of Maine soils. Growth and yield studies are available from the Penobscot Experimental Forest, which has been a valuable source of base data since 1950, and the project has been active in the development of mathematical models of the effect of various perturbations on the growth and yield of spruce and fir. In addition, research at Orono has indicated that a process of trace metal accumulation is occurring at low-elevation spruce-fir sites. Data gained from this research on pH concentration and the possible role of trace metals are being used in studying high-elevation spruce decline.

Parsons, West Virginia

Research is carried out on the calibrated watersheds of the Fernow Experimental Forest to determine the long-term changes in stream water chemistry as well as seasonal changes and changes during storm events. Instrumental and sampling procedures are used to investigate changes in the precipitation's pH as it filters through the forest canopy and soil profile. In addition, researchers are evaluating heavy metal concentrations found in the study area. Detecting any shifts in populations of macroinvertebrates in six small streams near Parsons will enable researchers to determine the relationship between acid deposition and these population shifts. Other studies are assessing the combined influence of acid deposition and forest management prescriptions on streamflow chemistry.

University Park, Pennsylvania

Researchers at University Park are assessing the impact of acid precipitation on water quality during episodic storm events in small headwater streams. Such water quality studies are critical because similar watersheds are a part of many municipal water supply systems. Long-term trend changes in stream acidity are also being evaluated. Research here determines the impact of acid precipitation and its runoff on urban forests. Information is being developed that defines deposition cycling in urban forests and techniques that can be used to moderate the impact of atmospheric deposition. Monitoring studies in conjunction with the Pennsylvania State University and the Pennsylvania Department of Environmental Resources are providing information on the changes in atmospheric deposition chemistry throughout the hardwood and softwood ecosystems of Pennsylvania.

Southeastern Forest Experiment Station

The Southeastern Station is coordinating studies on the effects of air pollution on forests in the Atlantic Coast states from Virginia to Florida. The Station and its cooperators in universities, state forestry organizations, and forest industry are participating in the National Acid Precipitation Assessment Program. A Southern Commercial Forest Research Cooperative, formed to measure forest effects of air pollution, is managed by the Southeastern Station. Effects of many man-made pollutants—sulfur and nitrogen compounds, carbon compounds, heavy metals, and ozone, singly and in combination—are under study.

Asheville, North Carolina

The Station's Forest Inventory and Analysis unit, headquartered in Asheville, has documented a long-term decline in the growth of southern pines, the most important timber species in the South. Data from its thousands of permanent survey plots are being reexamined for clues in the possible causes for decline. Air pollution in some form is one of many suspects.

Athens, Georgia

The Southeastern Station's largest concentration of scientists is at the University of Georgia in Athens. Technical leadership for many of the studies on effects of air pollution originates here. Increment cores have been extracted from southern pines from throughout the Southeast. They are being analyzed in Athens to determine exactly when growth may have slowed.

Durham, North Carolina

A major outdoor research facility is under construction on the Duke Forest to measure effects of controlled quantities of pollutants on trees. Research here by scientists from the public and private sector will be coordinated by the Station.

Research Triangle Park, North Carolina

Plans for a special survey of forest vegetation in the United States for signs of air-pollution damage are being made at the Research Triangle. Here also, economic effects of forest damage by air pollution are being estimated.

Raleigh, North Carolina

North Carolina State University has long been the leader in measuring the effects of acid rain on southern forest vegetation. The Southern Commercial Forest Research Cooperative is headquartered here, and effects of many air pollutants are being studied.

Forest industry is the second largest employer after agriculture in the Southeast and has invested vast sums in mills and in millions of acres of timberland. The region's forests also support a high recreation industry. The announcement of a slowdown in pine growth, therefore, sent shock waves through the Southeast. The forestry community and the public as a whole want to know what is happening to the region's forests and why. In some form, air pollution may be part of the problem. The Southeastern Station is leading the effort to understand and correct the situation.

COOPERATIVE UNDERSTANDING

Researchers are working to understand the complexities of acid rain in its various forms as it affects eastern forests. Evidence suggests that acid deposition is involved in the loss of ability of hundreds of lakes in the Adirondack Mountains to support fish populations. Atmospheric deposition in some form is believed by German scientists to have contributed to the death or dieback of up to one-third of Germany's forests including the famed Black Forest.

A forest is a complex system. Too much about the interactions between elements, compounds, minerals, and living things has escaped our understanding. When growth declines are discovered for some species of trees, or in a given area, there has been a temptation recently to suggest that acid deposition and acid deposition alone is the culprit. Researchers warn against viewing that simplistic image of acid rain as fact. They maintain that acid deposition acts in concert with other pollutants and stresses. The combinations of these pollutants and stresses may produce effects much more dramatic than any one factor could produce alone. In other words, they may react synergistically upon the forest.

Similarly, the research efforts described in this publication taking place at Hubbard Brook Experimental Forest, Coweeta Hydrologic Laboratory, and the laboratories and research units of the Northeastern and Southeastern Forest Experiment Stations; as well as cooperative efforts with universities, other government agencies, and private industry, will come together in a synergistic way. With such cooperative interactions, scientists hope to fully understand, and then recommend one or several courses of action to alleviate the effects of this complex phenomenon, popularly called acid rain.

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